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M532 BATTERY TELEMETER

by

Gordon A. Nicolaisen

January 1968

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U.S. ARMY MATERIEL COMMAND

HARRY DIAMOND LABORATORIES

WASHINGTON, D.C. 20438

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CONTENTS

ABSTRACT

A completely self-contained three-channel telemetry system for testing fuze power supplies on artillery or mortar projectiles is described. The telemeter consists of a transmitter, three subcarrier oscillators, in-flight calibrator, battery and signal-conditioning networks, all especially packaged to withstand linear accelerations up to 25,000 g and spin rates up to 22,000 rpm. Field tests indicate the telemeter performs reliably in this environment.

1. INTRODUCTION

The need for a rugged, reliable, low-cost, easy-to-use telemeter for monitoring the in-flight performance of fuze batteries provided the impetus for the development of the M532 battery telemeter. The telemeter is of the frequency-division multiplexing type (FM/FM), utilizing data-modulated subcarrier oscillators whose outputs are combined linearly, and the resultant composite signal then used to frequency modulate a rf carrier of approximately 240 MHz. In designing the telemetry system, the telemetry standards devised by the Inter-Range Instrumentation Group (IRIG) were used as guide lines. Three data channels are provided for monitoring battery operation, with an in-flight calibrator providing a voltage reference level at 1-sec intervals on each channel.

The telemeter is fabricated with modified fuze hardware, where possible, to keep costs down. Rugged construction has allowed units to be recovered under some test conditions and reused several times. The evaluation of the telemetry data is simplified by use of the in-flight calibrator, which permits data voltages to be easily determined from the telemetry records.

The fuze batteries being monitored are one-shot devices. Therefore, if the telemeter is to be reusable, provision for easily connecting test batteries to the telemeter must be provided, and the telemeter power supply must be rechargeable. The design provides for both.

2. SYSTEM DESIGN

The telemetry system consists of three major subassemblies plus signal-conditioning circuitry (fig. 1, 2). The subassemblies are:

a) transmitter,

b) subcarrier oscillator (SCO) including in-flight calibrator, mixer, and voltage regulator,

c) NiCad power supply (including g-switch).

The transmitter is of the cap-loaded type using the projectile body as the radiating element. It consists of a single overlay type (2N3553) transistor in a grounded-base Colpitts oscillator circuit. The oscillator is frequency modulated by applying the modulating signal at the transistor base.

The subcarrier oscillators are of the multivibrator type with a low-pass filter at the output to provide a sinusoidal waveform over a ±7.5-percent bandwidth around the center frequency. The output of the three SCO's is mixed in a linear resistive mixer-amplifier and then fed to the transmitter. An in-flight calibrator is used in conjunction with each SCO channel to provide a zero and maximum input voltage reference level once each second during flight.

A series transistor-type voltage regulator provides a regulated output of approximately 13 V to all telemeter circuitry.

A supply of 15 NiCad cells in series powers the telemetry system. A special double-acting g-switch provides turn-on and turn-off capability for low-acceleration (under 1000 g) projectile firings when recovery of the round can usually be accomplished. In this case, the g-switch closes upon firing and opens on impact. To assure positive turn-on at high accelerations, an SCR is actuated by the g-switch to provide a latch-on function. The SCR is disabled for low-g turn-off operation.

2.1 Cap-Loaded Transmitter

The transmitter consists of a single overlay-type transistor (2N3553) in a grounded-base Colpitts oscillator circuit as shown in figure 3. Final operating frequency is 237 ± 5 MHz. The oscillator components are mounted on a steel can using small glass stand-off terminals and feed-through capacitors for support. The single transistor is mounted in the center to minimize spin effects. In addition, the TO-5 transistor case is internally potted with epoxy for withstanding high accelerations. Good frequency stability over a wide range of temperatures is obtained by use of a capacitor with a negative temperature coefficient between collector and emitter (C3).

The oscillator tank consists of a single turn of wire. Oscillator frequency is adjusted easily by kinking the wire to change inductance. The antenna cap is mounted on an epoxy-fiberglass ring secured to the transmitter can by an epoxy bond and four steel screws. The completed assembly is then potted using a mixture of sand and epoxy. The transmitter layout is shown in figure 4. The dielectric loading of the epoxy-sand mix causes the frequency to drop approximately 13 MHz to a final operating frequency of 237 MHz.

The rf deviation sensitivity of the transmitter is adjusted by selection of resistor R_4 to ±125 kHz/V pp.

The transmitter radiates more than 150 mW. Input power required is 60 mA at 13 V. Antenna patterns on projectiles such as 81-mm mortar and 105-mm artillery rounds are similar to that of a dipole mounted along the projectile axis. However, the major lobes lean back to the rear up to 30 deg on the smaller projectile (81-mm mortar). On 175-mm projectiles, two small forward lobes are generated with a more pronounced lean-back of the major lobes.

2.2 Subcarrier Oscillator Assembly

The subcarrier oscillators are frequency modulated by the information function to be monitored — in this case a voltage level. The oscillators consist of a free-running symmetrical multivibrator and an output low-pass filter. The multivibrator operates at a preset frequency in its free-running conditon and is deviated in frequency proportionately by a change in input control voltage (bias) to a total of about 15 percent of its zero voltage input frequency.

The square-wave output of the multivibrator is fed to a low-pass filter, which reduces the harmonic content of the signal to a level sufficient to prevent crosstalk.

Three IRIG standardized subcarrier oscillators with identical circuitry are used (fig. 5). The SCO timing capacitors C_1 and C_2, bias resistor R_1, R_7, and low-pass filter values are varied to obtain the frequencies, deviation limits, and nominal frequency response shown in table I.

Table I. SCO Frequencies

IRIG Channel	Center Frequency (Hz)	Lower Deviation Limit (Hz)	Upper Deviation Limit (Hz)	Nominal Frequency Response (Hz)
14	22,000	20,350	23,650	330
16	40,000	37,000	43,000	600
18	70,000	64,750	75,250	1050

The nominal frequency response shown in table I is based on a modulation index of 5. The SCO's are adjusted (R_1, fig. 5) to their lower deviation limit with zero input. Deviation sensitivity is adjusted (R_7, fig. 5) so that an input of +5 V causes the SCO frequency to shift to its upper deviation limit.

The circuit boards used in the SCO assembly are shown in figure 6. Low-cost, encapsulated transistors are used throughout. All components were especially selected and tested for their ability to withstand the high-acceleration environment. The SCO's are not individually temperature compensated for frequency stability, since the use of a two-point in-flight calibrator permits rather large frequency changes (±5 percent). The simple compensating network uses a silicon temperature-compensating resistor (R_3, fig. 5) in a bias divider to vary the voltage as a function of temperature. The three-pole LC low-pass filter at the output, in conjunction with an emitter-follower, provides low-amplitude modulation, low harmonic distortion (less than 2 percent), and low output impedance.

In a frequency-division telemeter system, equal subcarrier amplitude-to-noise ratios in all channels are obtained by setting rf carrier deviations proportional to the 3/2 power of the SCO center frequencies. With the system set up in this manner, the signal-to-noise ratio threshold for each SCO channel is reached at the same rf signal level.

The mixer output of each SCO is combined in a resistive mixer consisting of three mixing resistors and the base bias circuit of an emitter follower (fig. 7). The value of the three mixer resistors is adjusted to provide a subcarrier pre-emphasis taper proportional to the 3/2 power of the subcarrier center frequency. The mixer resistors also attenuate the SCO output to provide a composite signal having a peak-to-peak amplitude of 1 V, thus matching the transmitter deviation sensitivity characteristics to produce rf deviations of ±125 kHz.

2.2.1 Voltage Regulator

SCO frequency, calibrator period, and transmitter rf deviation sensitivity vary with supply voltage. Good regulation is therefore required for stable performance.

The regulator circuit is shown in figure 7. The series transistor Q_2 provides a regulated output of 12.8 ± 0.3 V at 70 mA with an unregulated input of 16 to 18 V. The reference voltage is derived from a 13-V Zener diode with two forward-biased diodes in series for temperature compensation and to offset the base-emitter drop of Q_2, the series regulator transistor. The 22-μF capacitor across the regulator output reduces ripple caused by the millivibrator loads.

2.2.2 Two-Point In-Flight Calibrator

The in-flight calibrator (center circuit board in fig. 6) provides a zero input and a maximum (+5 V) input reference level at approximately 1-sec intervals when the telemetry system is in operation. Each SCO channel is provided with a set of transistor switches to perform this function. The transistor switches (shown as simple, single-pole switches S_1, S_2, and S_3 in fig. 8) are driven by an unsymmetrical free-running multivibrator and monostable multivibrator. The calibrator switching functions and timing are shown graphically in figure 8. The operation is as follows:

a) S_1, a field-effect transistor, opens for 50 msec.

b) When S_1 opens, S_2 closes for a 25-msec period, shorting the SCO input to ground.

c) S_2 then opens and S_3 closes for 25 msec, applying +5 V to the SCO input.

d) When S_3 opens, S_1 closes, and the calibration cycle is complete.

A schematic diagram of the in-flight calibrator is shown in figure 9. Regulated voltage is supplied to two multivibrators and a 5.6-V Zener diode reference voltage network. The circuit operates as follows: Transistors Q_1 and Q_2, in an unsymmetrical free-running multivibrator, provide gating pulses of 25-msec duration at 1-sec intervals. The gating pulse from the collector of Q_2 is applied to the base of Q_5, Q_7, and Q_9 (switch S_2 in fig. 8), turning them on and connecting the three SCO inputs to ground. At the same time, the pulse from the collector of Q_1 is differentiated, and the positive-going pulse occurring at the trailing edge of this pulse is used to trigger the monostable multivibrator whose time constants are adjusted to provide a cycle time of 25-msec. The pulse developed at the collector of Q_4 is then applied through current-limiting and isolating resistors to the bases of Q_6, Q_8, and Q_{10} (represented by S_3, fig. 8). When these transistors turn on, they raise the input of each SCO to the +5-V level for 25 msec. Normally closed field-effect transistor (FET) switches (S_1 in fig. 8; Q_{11}, Q_{12}, and Q_{13} in fig. 9) in series with the data input are opened for 50 msec by output from Q_2 and Q_4 fed through an AND gate consisting of a resistor and diode in the FET gate circuit. Use of the FET in series with the input prevents the signal-conditioning circuits from affecting the calibrator operation and vice versa.

The reference voltage used in the calibrator is obtained from a 5.6-V Zener diode with a divider across it. The divider resistors are easily selected to provide a level of $+5.00 \pm 0.05$ V. The a-c impedance of this reference source is kept low by placing a large capacitor across the divider output. A low source impedance prevents the calibration pulse from dropping during the 25-msec calibration interval.

2.3 Power Supply

The power supply consists of 15 sealed, "pressed"-plate, 50-mAh nickel-cadmium cells in series with a special g-switch and SCR for turn-on at launch. The completed assembly, fully encapsulated in epoxy, delivers a minimum of 16 V at 100 mA for periods up to 3 min at temperatures above 0°C. The power supply is shown schematically in figure 10. Supplies of this type have been used to power telemeters with launch accelerations up to 70,000 g with excellent results. Supplies fabricated as shown in figure 11 have been test flown at spin rates up to 360 rps, have been recharged many times, and have a shelf life of at least 1 year.

The g-switch uses a standard component holder modified and mounted in a small molded plastic box. A silver-plated drill-rod slug, rounded at both ends, is placed in the component holder. Holder tension is adjusted so that the slug will not move until setback is greater than 500 g. The component holder is cut into two pieces with a lug connected to each. Under acceleration, the slug moves to short the two lugs together, thus acting as a single-pole switch. At high-g levels, where the slug might bounce back to the open position when striking the end of the plastic box, the SCR (fig. 10) is turned on by the g-switch supplying gate current through R_1. When recovery of the telemeter is possible, such as when fired at one propellant increment on a mortar shell, points 1 and 2 are jumpered to short out the SCR and allow the g-switch to turn the system off on impact to conserve TM battery power.

2.4 Signal Conditioning

Signal-conditioning circuitry used with the battery telemeter is needed to adapt the output of the device being monitored to the deviation limits and impedances of the SCO. The SCO's have input impedances greater than 200,000 ohms, and their deviation sensitivity is set at 0 to +5 V. Typical signal-conditioning circuit boards are shown in figure 12. The PS115 circuit board has two identical circuits for monitoring two batteries at a time.

The PS115 battery is a low-cost, liquid-reserve power supply for fuze applications. Voltage level and battery noise are parameters usually required for fuze design. The signal-conditioning amplifier and divider shown schematically in figure 13 were used to divide the 35-V output down, by a factor of 14 to 1, to 2.5 V and, at the same time, combine the amplified noise components. Three amplifier stages were used to prevent oscillation. With both collector and emitter feedback at each stage, high gain stability was obtained.

The PS201 battery is used to power a fuze with vacuum-tube circuits. Its output is 150 and 1.5 V. The signal-conditioning voltage-divider circuit for the PS201 battery is shown in figure 14. The 10-kohm load across the 150-V output and the 2.5-ohm load across the 1.5-V output are provided to simulate typical fuze loads. This type signal conditioning provides data such as that shown on the telemetry record in figure 15. The input to the 40-kHz SCO is obtained from a 30/1 voltage divider. The input to the 70-kHz SCO is from a 60/1 divider with a capacitor across the top leg. This allows noise voltages to be coupled directly into the SCO input with little attenuation at frequencies above 100 Hz. The PS201 signal-conditioning board (fig. 12) is provided with connector pins arranged to conform with the M532 fuze base layout. This allows test batteries, temperature conditioned either hot or cold, to be quickly and easily connected to the signal-conditioning circuits.

3. FIELD TESTS

Field tests of battery telemeter design performance began with a firing on 175-mm projectiles in mid-1965. Later, 81-mm mortar rounds and 105- and 175-mm artillery rounds were used to test more than 60 telemeters. Most tests used a single receiving station. On the 81-mm mortar and 105-mm artillery round test firings, some telemeters were subjected to extremes of range and powder increments. Ranges of 3000 ft and flight times of 13 to 17 sec were obtained after launch accelerations of about 1000 g on 1-increment 81-mm mortar tests. Telemeters were then recovered and in many cases, fired a second time on the same day with a new test battery. Several telemeters have been fired up to six times without difficulty. Results of all field tests performed to date are compiled in table II. In general, good data have been obtained on 90 percent of the 81-mm test flights where fuze battery performance was being monitored.

A portion of a typical flight test record on a PS201 battery is shown in figure 15. Here, the 22-kHz SCO channel uses a +2-V calibration level instead of the present +5 V. The NC53 battery referred to in table II is a liquid-reserve type, which uses spin to distribute the electrolyte after setback. Its output is nominally 18 V at 100 mA. This battery has been used to power the telemeter on tests where high spin rates are involved.

4. CONCLUSION

A completely self-contained telemetry system was developed and fabricated for testing fuze power supplies. Field tests over a wide range of conditons on several different vehicles indicate reliable

performance. The telemeter is being procured in limited production quantities at a cost under $600 each. Further reduction in cost may be achieved by production engineering and specification changes.

ACKNOWLEDGMENTS

The author wishes to express thanks for the assistance given by Paul Q. Prince, Wesley T. Creamer, and William L. Giokas in the assembly of test units and for the collection of data and illustrations used in this report.

Table II.— Battery Telemeter Field Tests

Battery TM No.	Test Round	Test Battery	Test Date	Remarks
5,6,7,8	175-mm	PS107	6/65	No operation; no data; mechanical failure of all units.
9,10,11,12	105-mm	None	7/65	Transmitters same as No. 5-8 but modified to improve mechanical strength; No. 9-10, no signal; NiCad batteries may have failed under spin; No. 11, 12, OK; used NC53 batteries.
13,14,15, 16	105-mm	None	9/65	New common base; cap-loaded TX design; one unit operated.
17,18,19 20,21	81-mm mortar 9 incr	PS201A Noisy lot	10/65	New TX mechanical layout; 4-channel SCO's; data from all units.
28,29,30 31	105-mm 7 incr	None	3/66	Special TX spin test; NC53 batteries; 3 units OK.
32,33,34 35,36,37	81-mm mortar 9 incr	PS201A	1/66	Data from 2 stations on all units.
38,39,40 41,42	81-mm mortar 9 incr	PS201A at -40°F	3/66	No. 42, no operation; all others OK; all units had new test battery connector.
43,44,45 46,47,48	81-mm mortar 5 incr	PS201A at +125°F	3/66	No. 43, no operation; all others good data.
49,51,52 53,54	105-mm Max. 1 incr	Two PS115's	8/66	Vertical recovery test; No. 54, no operation; others OK; TM power, NC53 battery.
63,63-2,55 56,58,58-2[a] 57,60	81-mm mortar 1 incr	PS201A at -40°F	8/66	Good data on all units; all units recovered; No. 58 & 63 fired second time & recovered.
55,56-2 56-3,58-3 58-4,57-2, 60-3,60-4 62-2,62-3 63-3,63-4 64,65,65-2 66	81-mm mortar 1 incr	PS201A at -40°F	10/66	Data on 16 rounds; all recovered;
55-3,56-4 57-3,58-5 60-5,62-4, 63-5,64-2 66-2,60-6 63-6,62-5 66-3	81-mm mortar 1 incr	PS201A at -40°F	11/66	Data on 13 rounds; units fired more than once and recovered.

[a] This notation means second firing of battery telemeter No. 58.

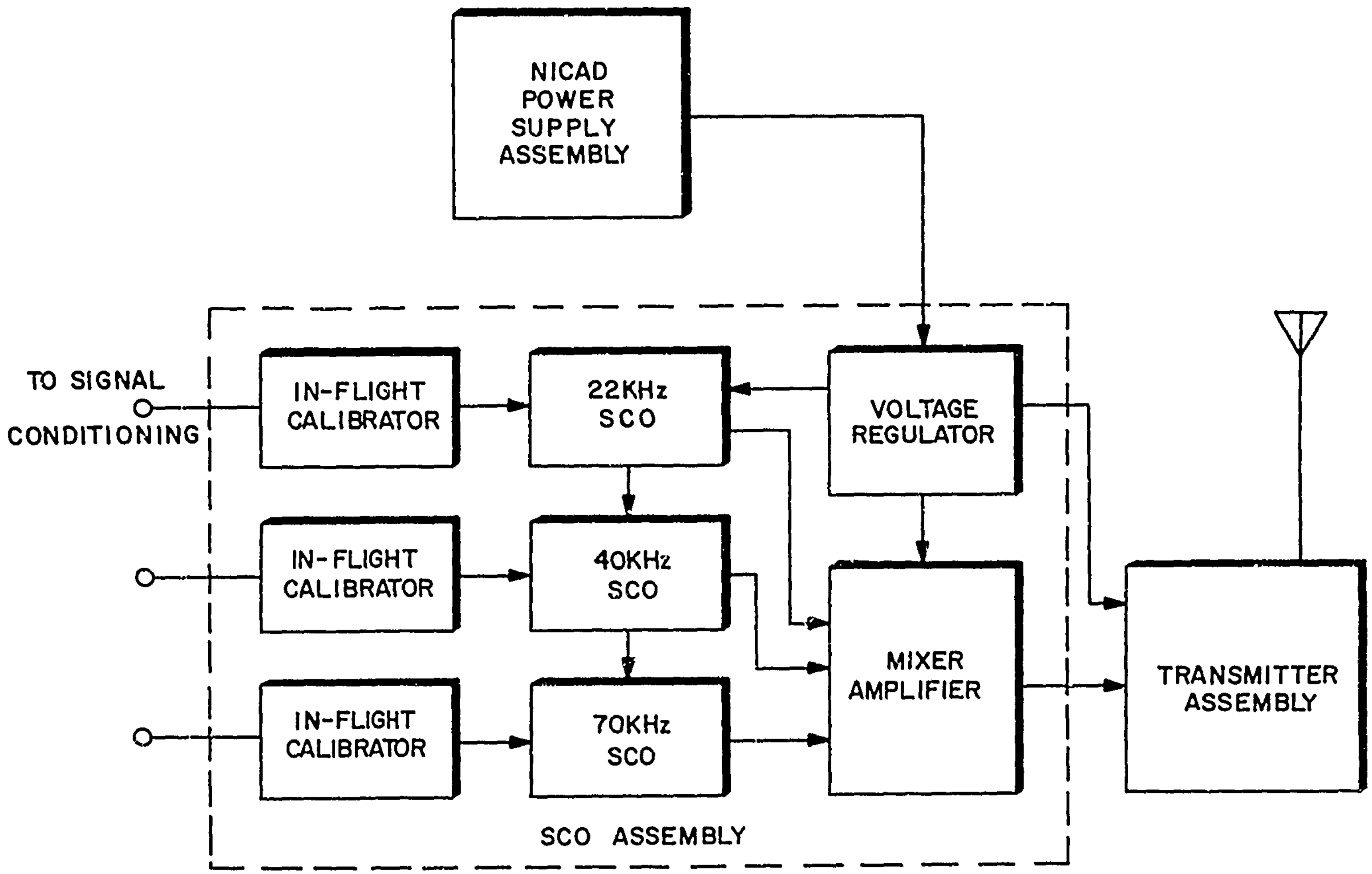

Figure 1. Block diagram of battery telemeter.

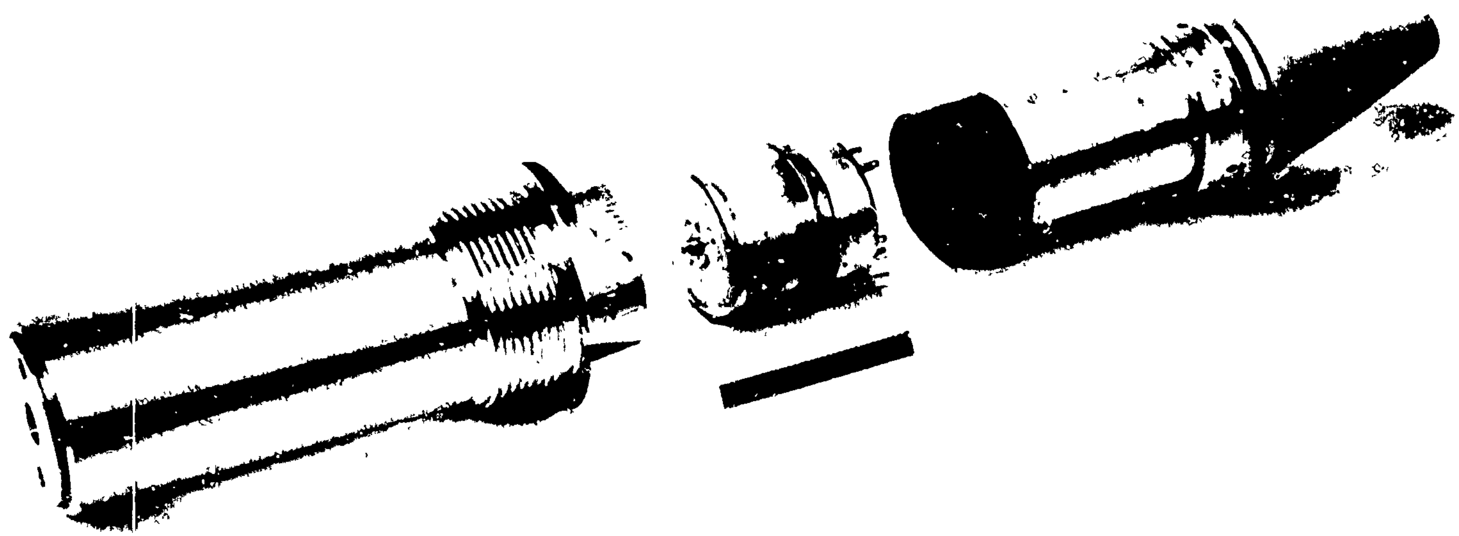

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Figure 2. Battery tclemeter with PS201 test battery and mounting sleeve.

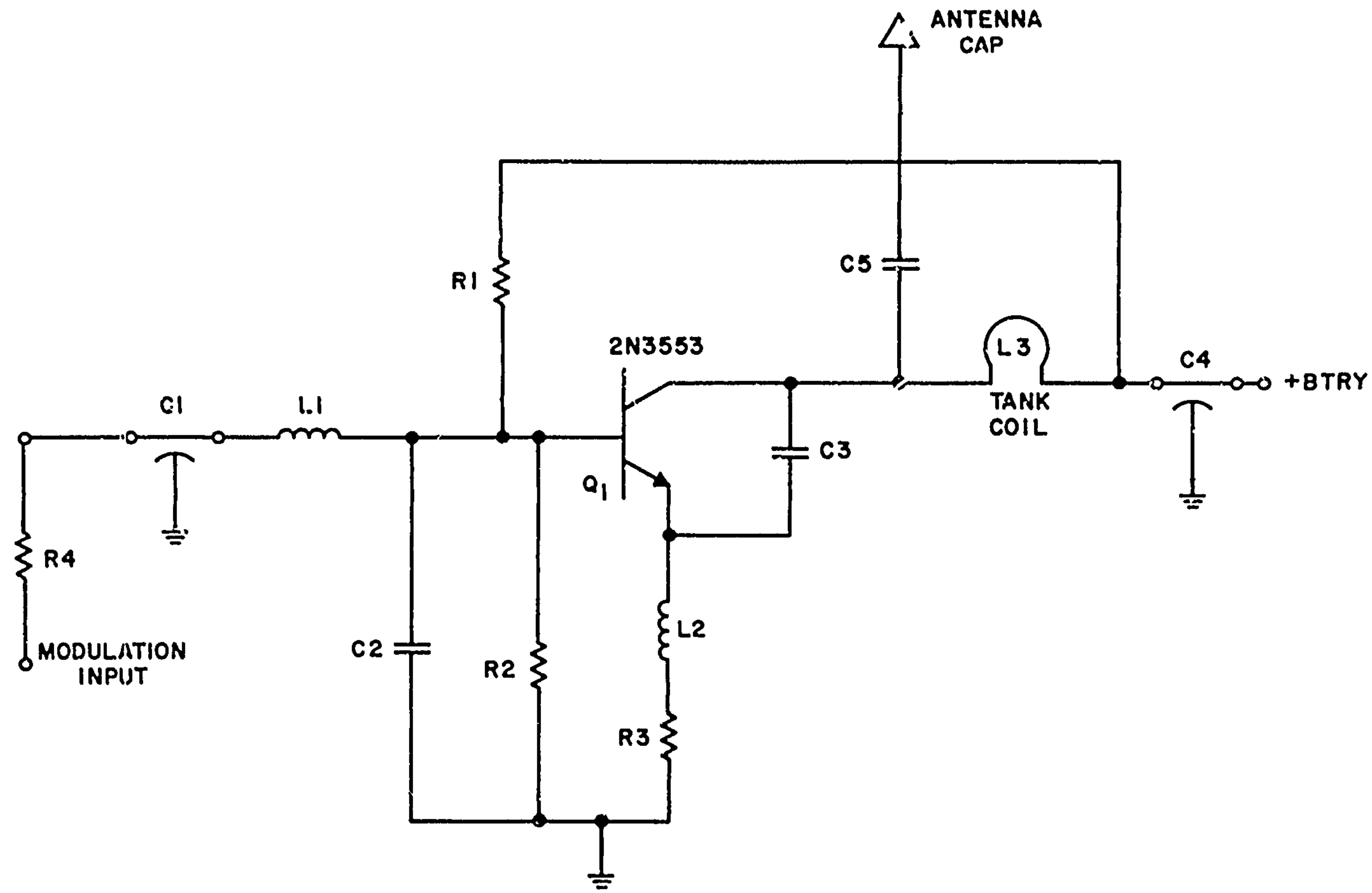

Figure 3. Transmitter-oscillator circuit.

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Figure 4. Battery telemeter oscillator assembly.

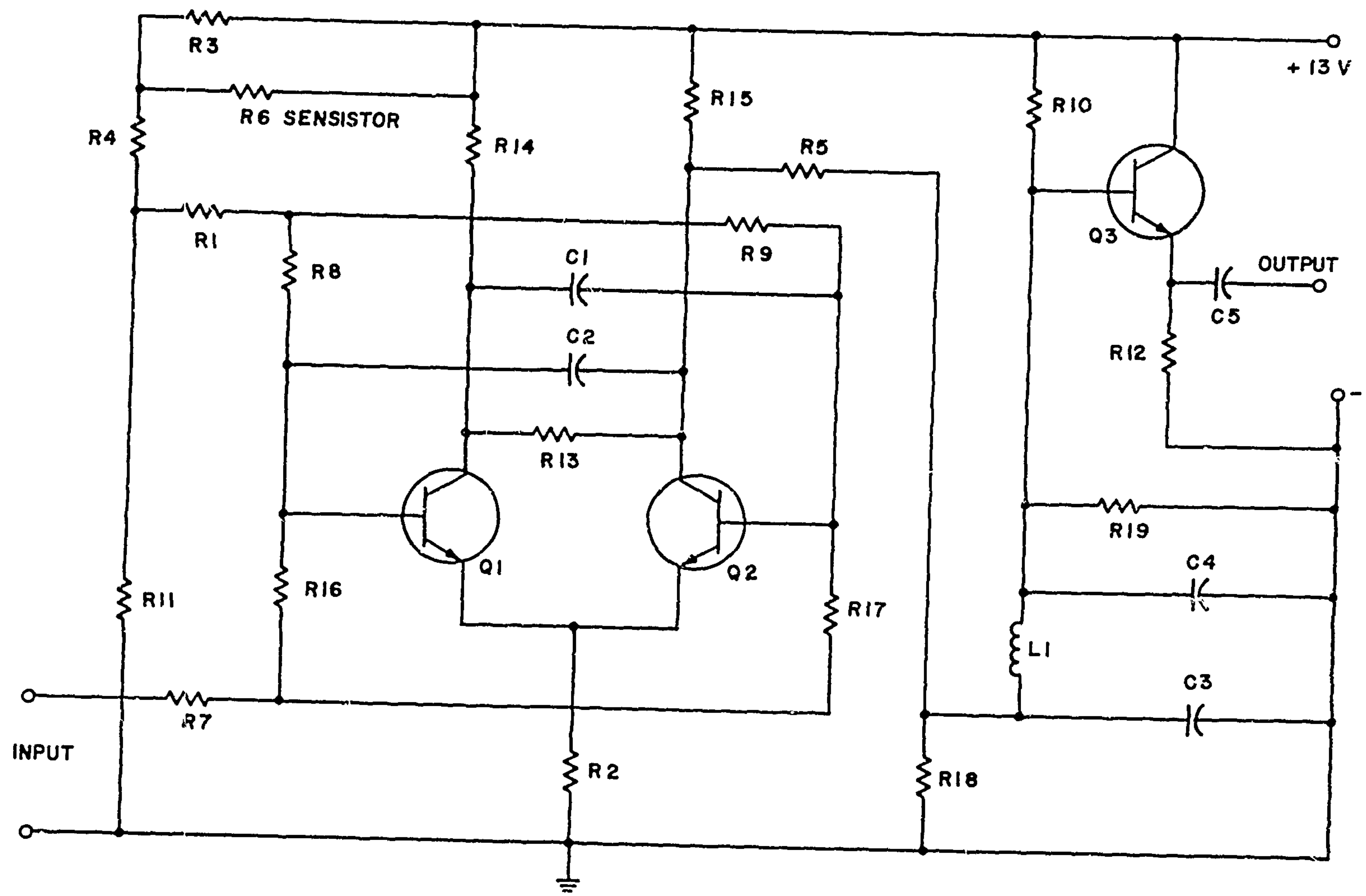

Figure 5. Subcarrier oscillator circuit

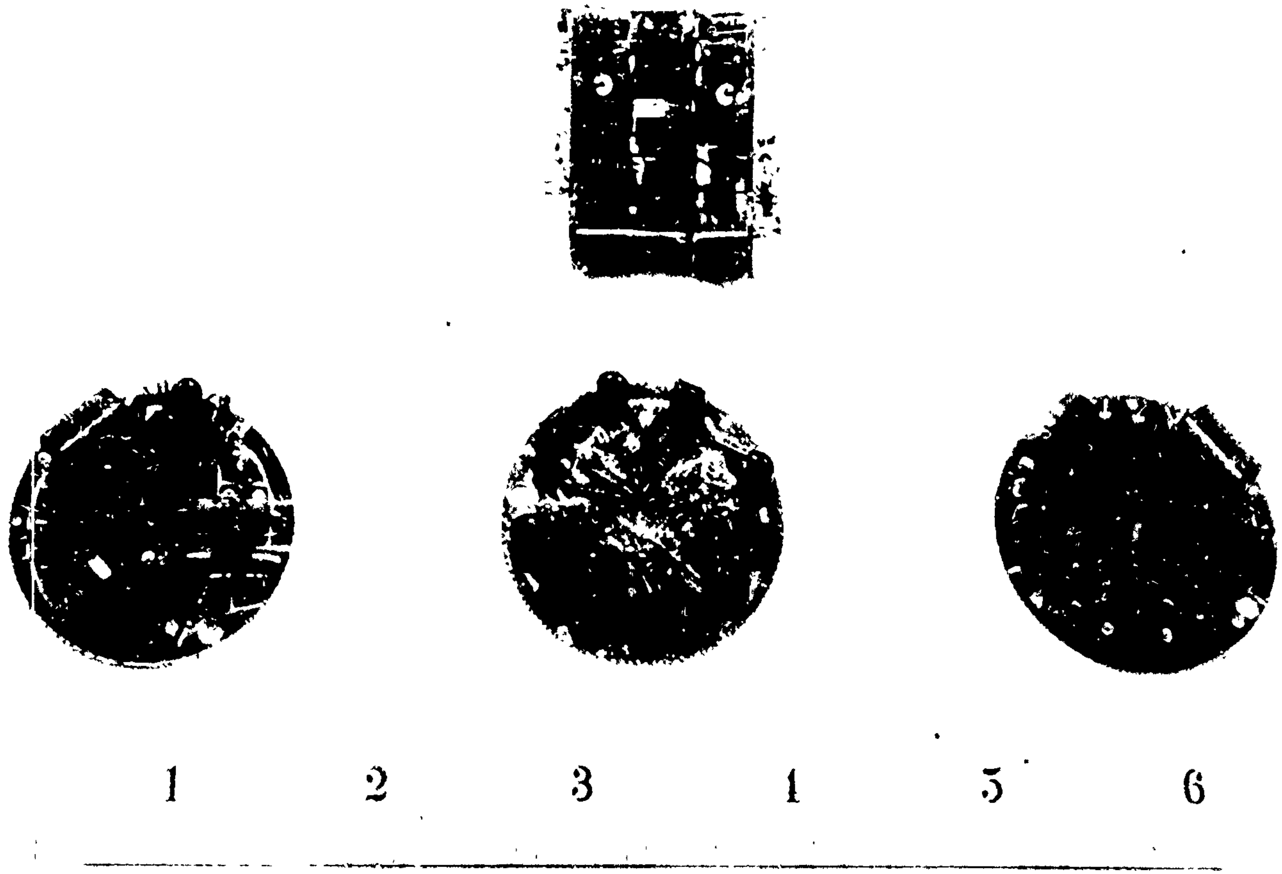

Figure 6. Subcarrier oscillator circuit boards. 1327-67

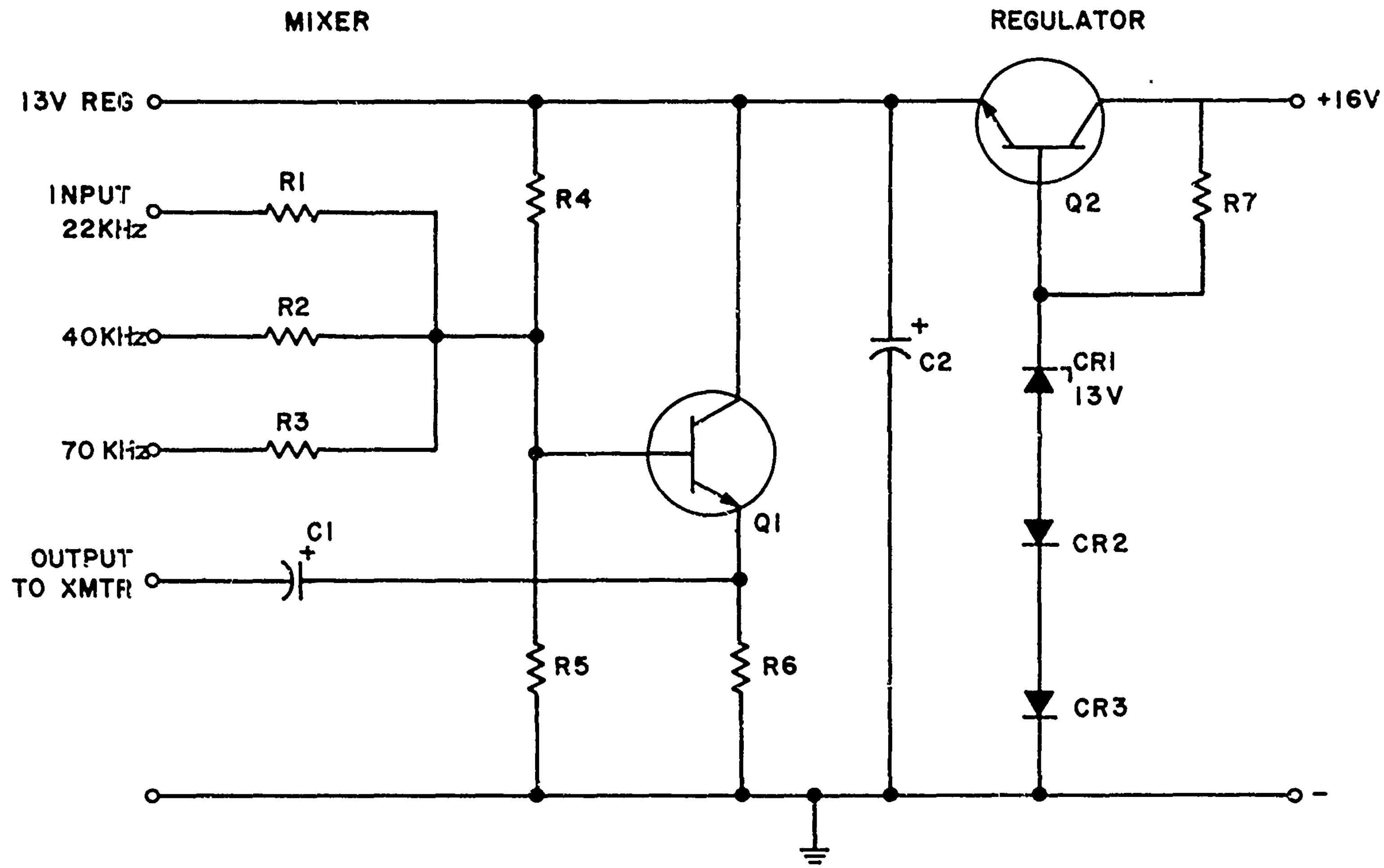

Figure 7. Mixer amplifier and voltage regulator.

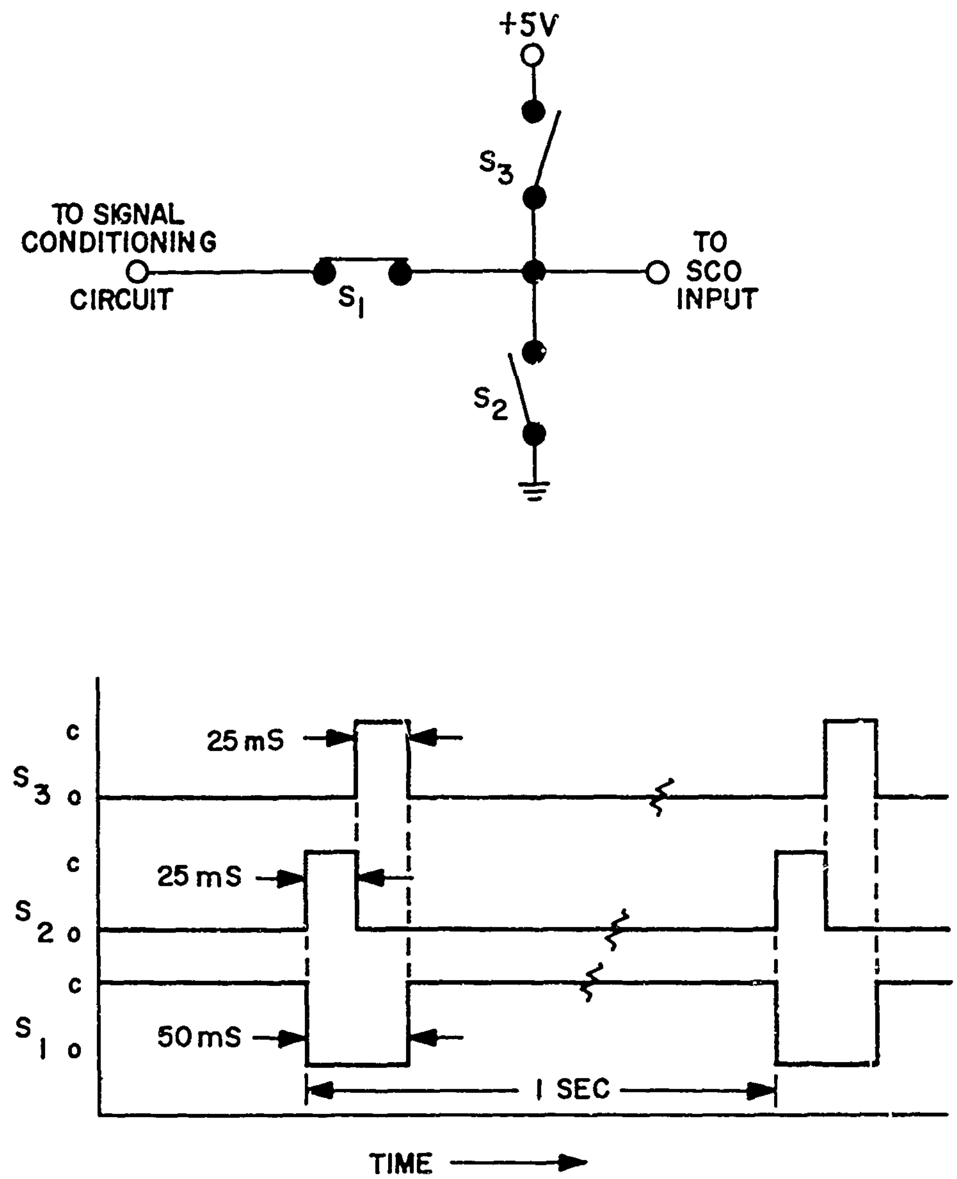

Figure 8. In-flight calibrator switching function and timing chart.

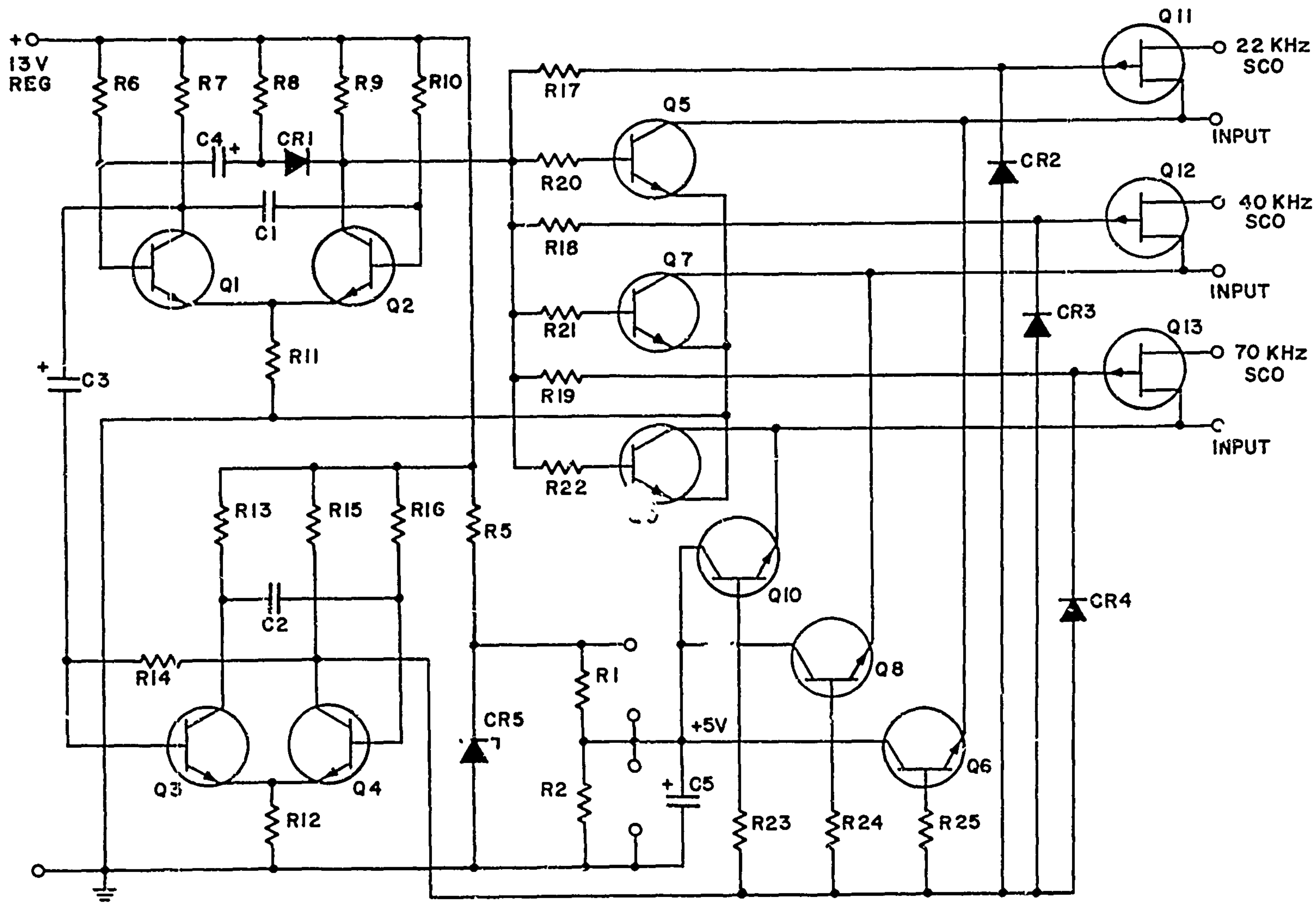

Figure 9. Three-channel two-point in-flight calibrator.

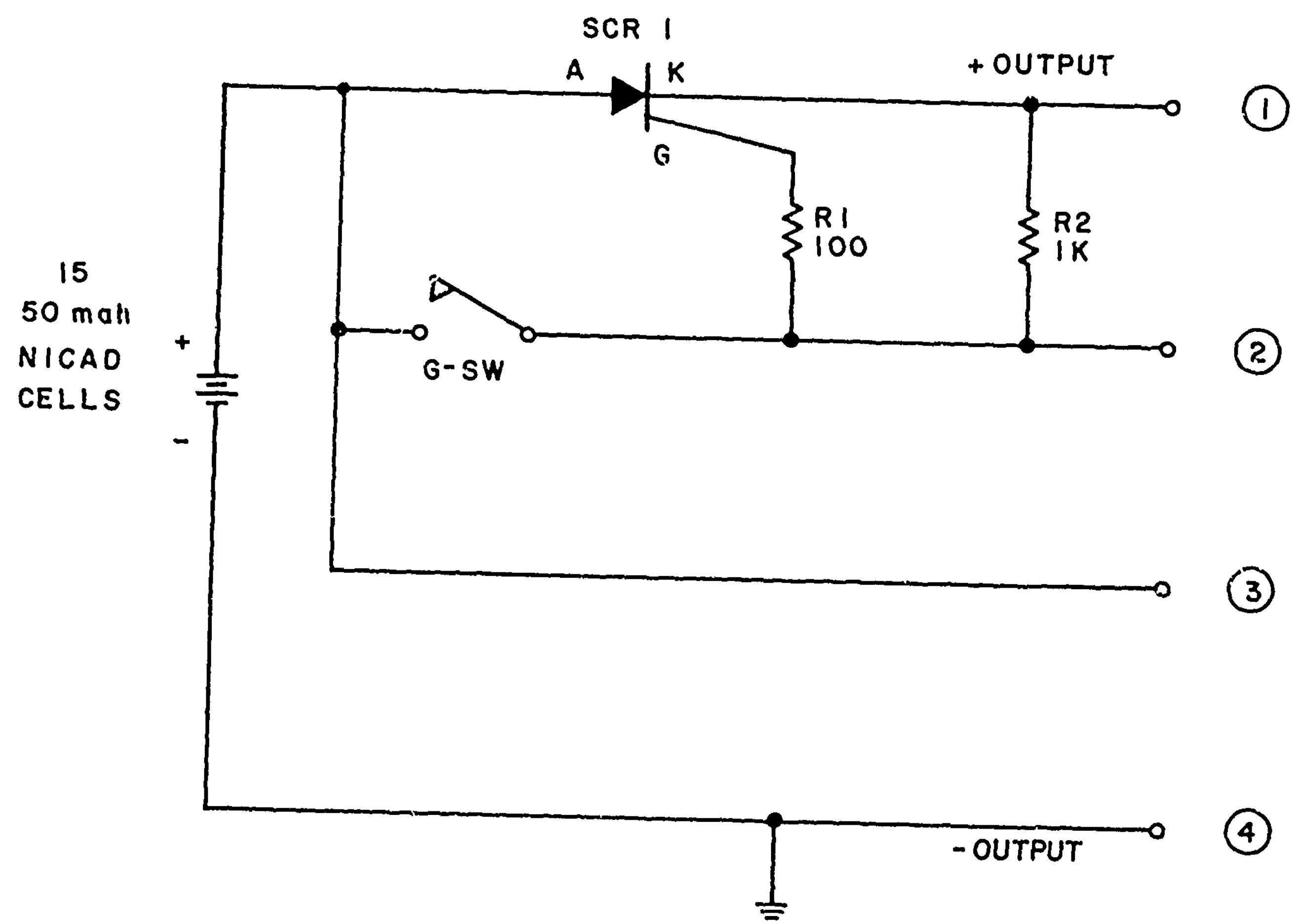

Figure 10. Telemeter NiCad power supply.

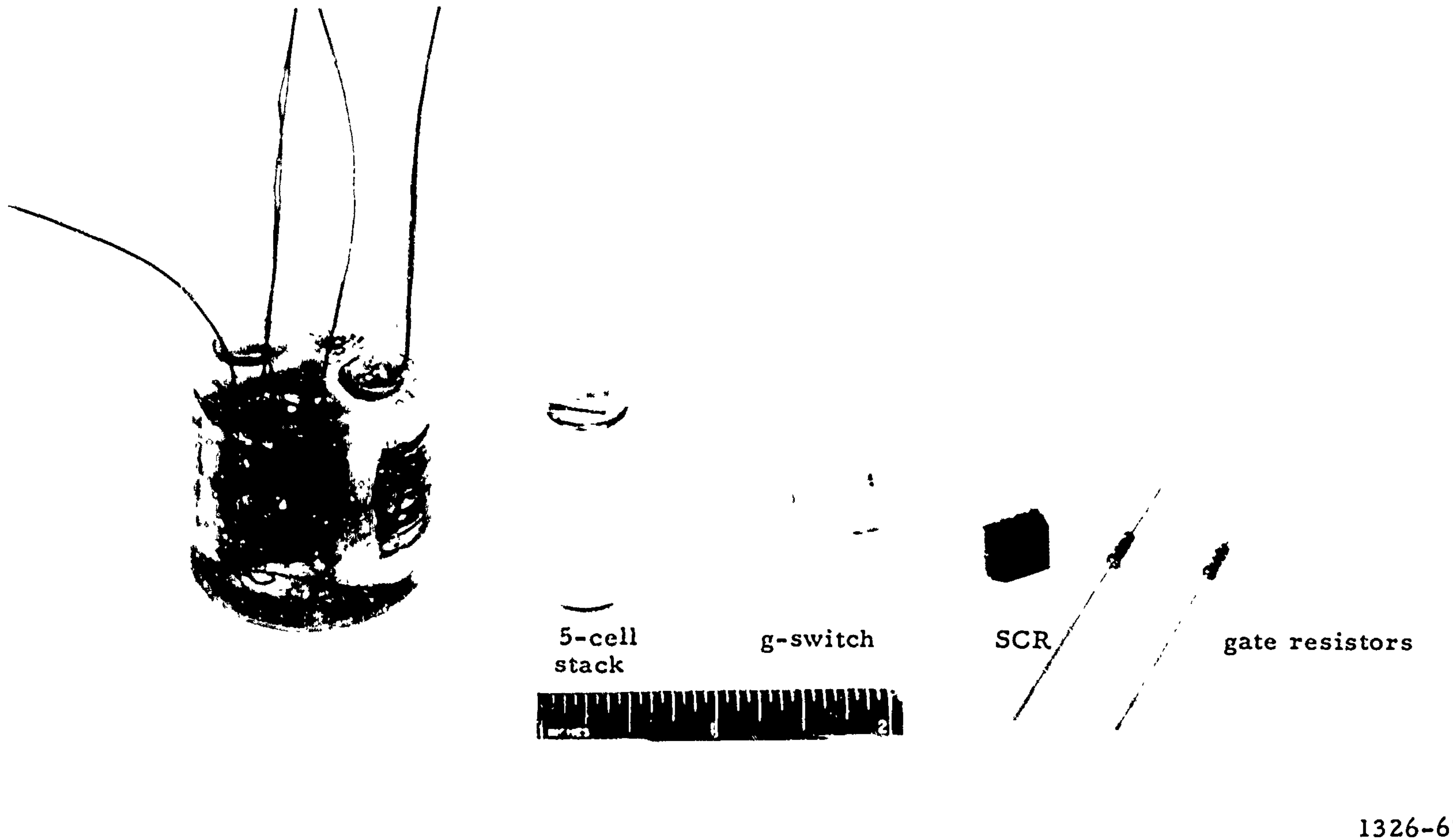

Figure 11. Telemeter NiCad power supply.

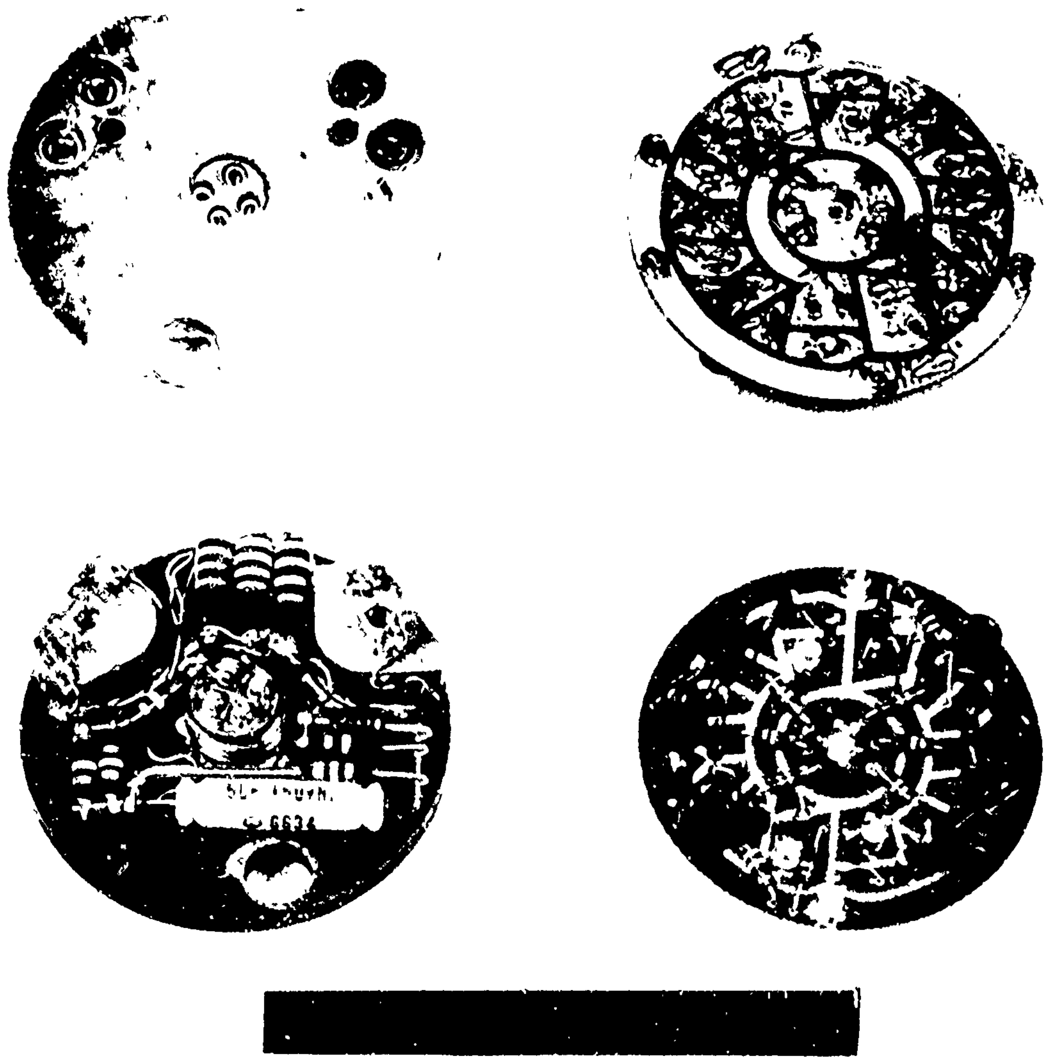

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Figure 12. Signal conditioning circuit boards, PS201 left, PS115 right.

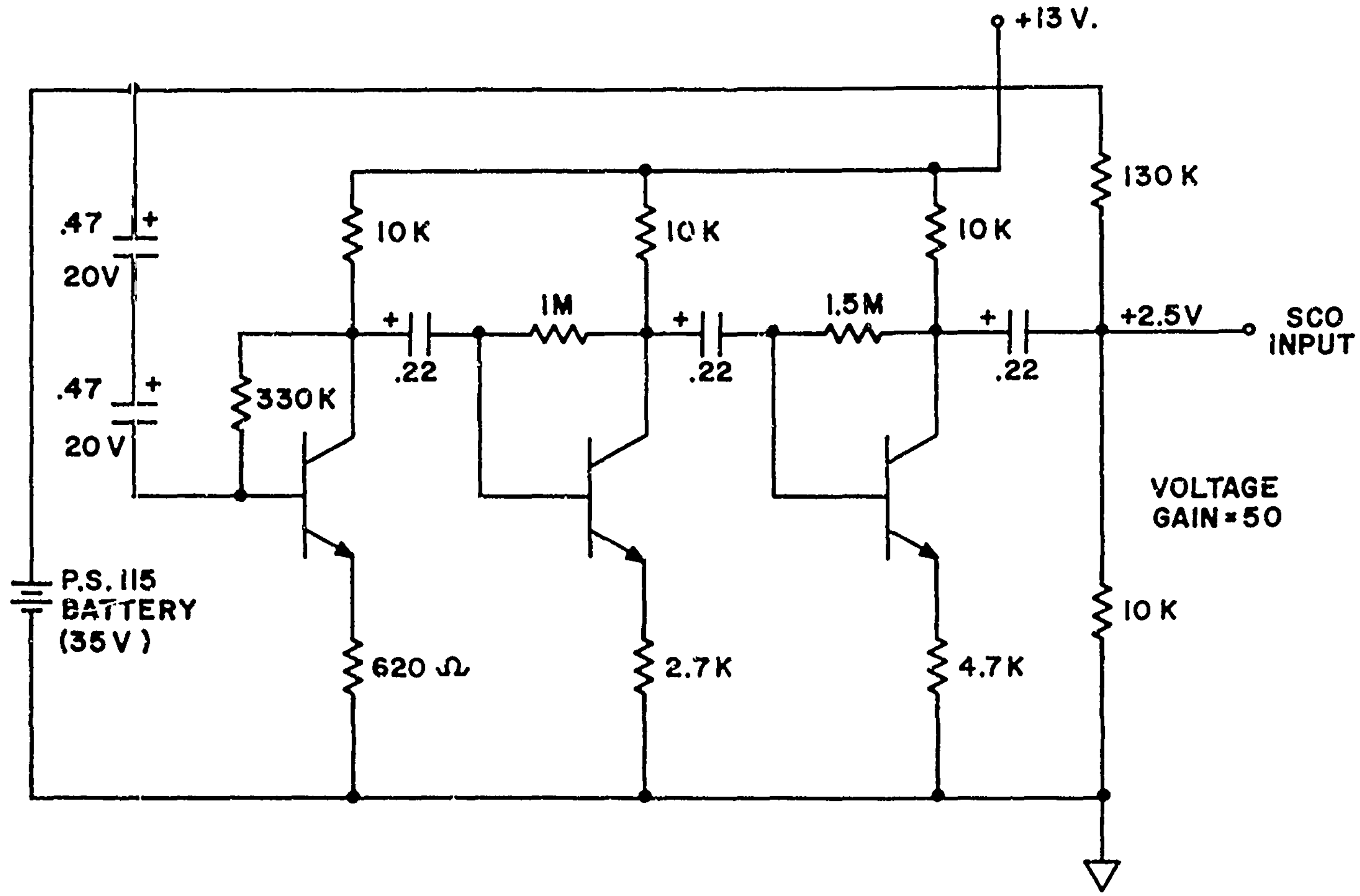

Figure 13. PS115 signal-conditioning amplifier and voltage divider.

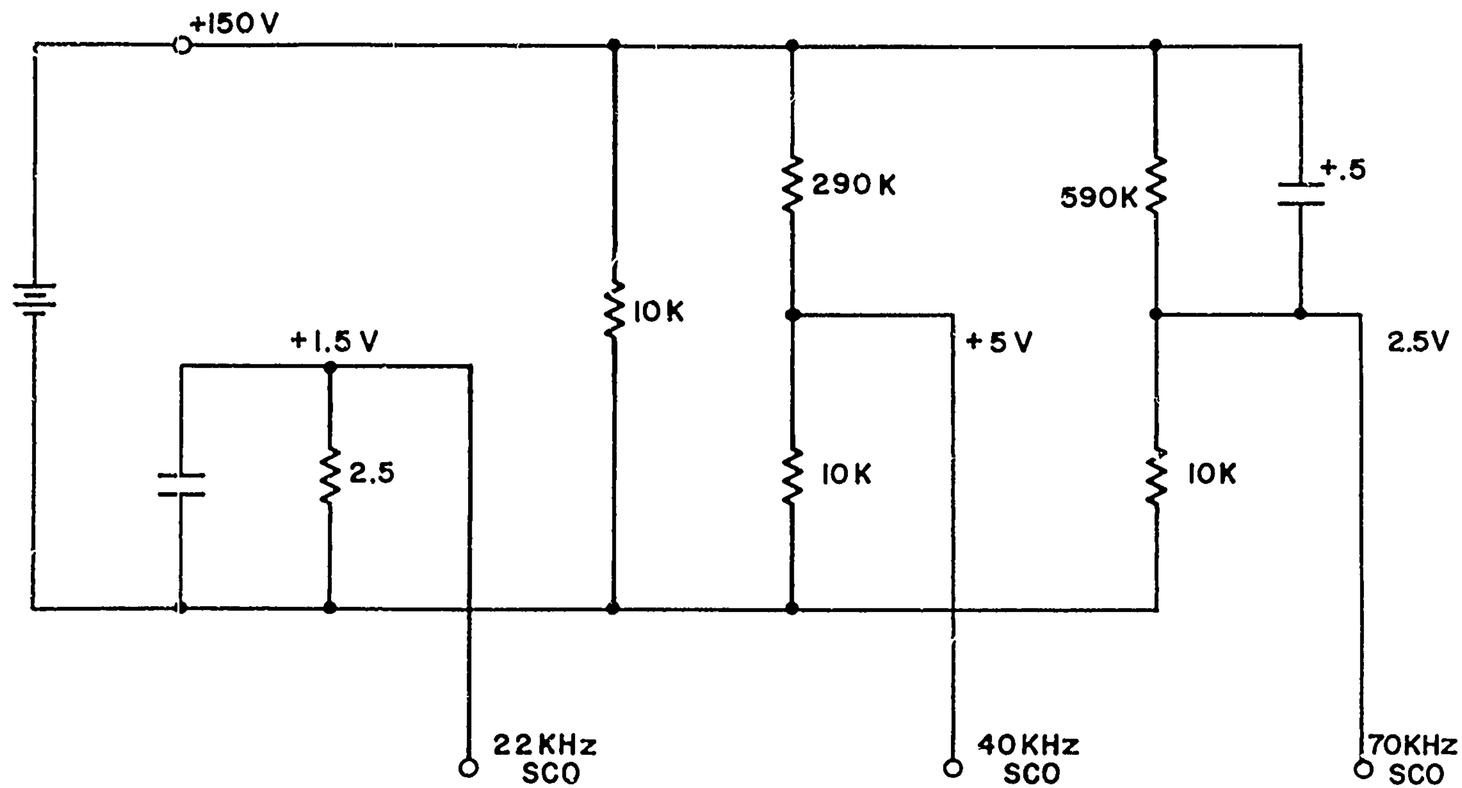

Figure 14. PS201 battery signal-conditioning voltage dividers.

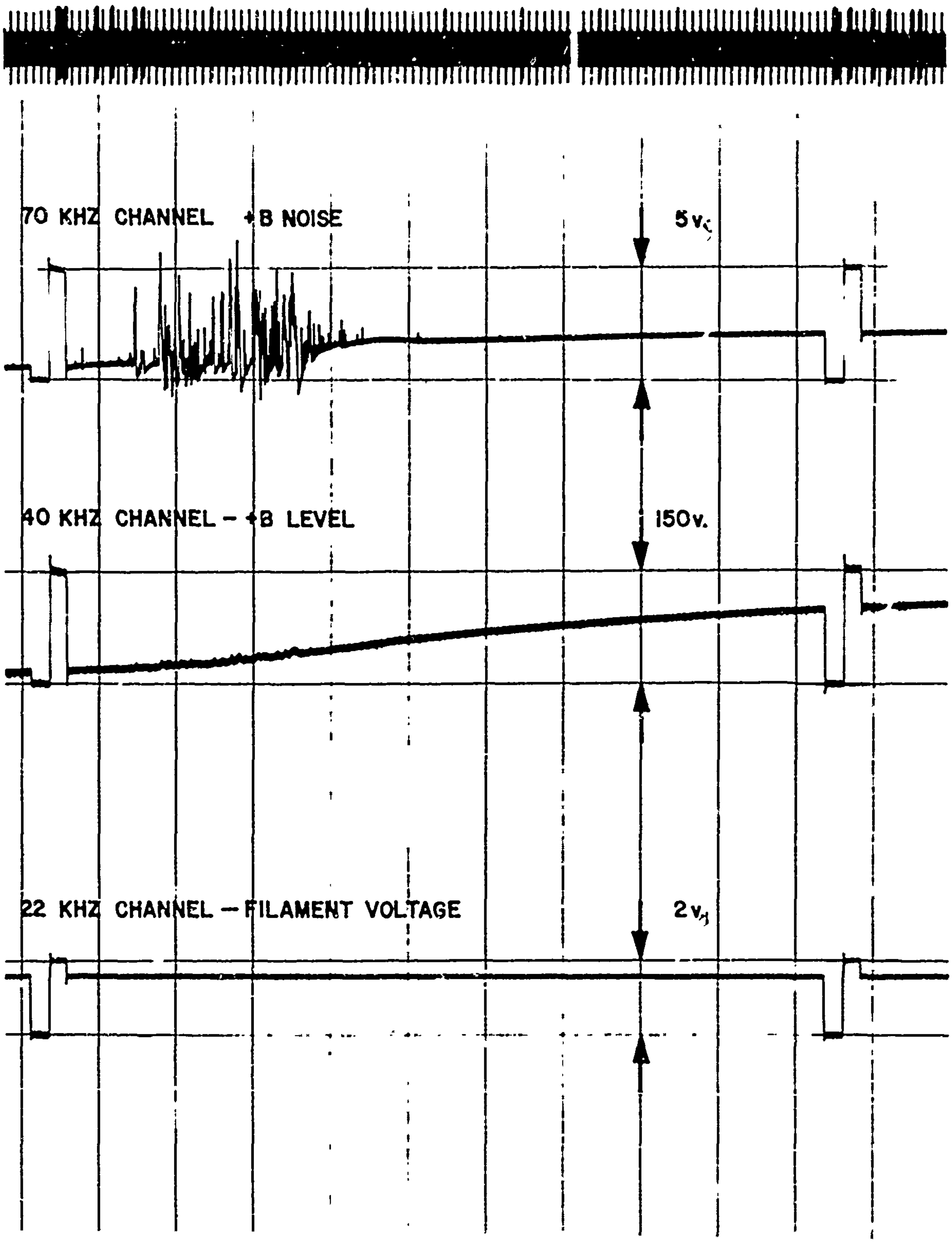

Figure 15. Typical PS201 battery telemetry test record.

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13. ABSTRACT

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Telemetry						

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